The High Power Targetry R&D Roadmap for High Energy Physics Workshop
@Fermilab, USA

31st May, 2017

High Power Targets at J-PARC #1

High Energy Accelerator Research Organization, KEK

J-PARC Center, Materials and Life Science Experimental Facility, Muon Section

Shunsuke Makimura

#1 (This presentation)

- COMET target at Hadron Experimental Facility
- ADS target at Transmutation Experimental Facility
- Muon & Neutron Target at Materials and Life Science Experimental Facility

#2 by Ishida-san and Chris

- Hadron target at Hadron Experimental Facility
- Neutrino target at T2K

CONTENTS

- Overview of J-PARC and Targets at J-PARC
- COMET target at Hadron Experimental Facility
- ADS target at Transmutation Experimental Facility
- High energy physics

at Materials and Life Science Experimental Facility

- Targets at Materials and Life Science Experimental Facility
- Summary

This presentation is supplied by

Mihara and COMET collaboration

Sasa, Meigo and ADS section

Maruyama and Sterile Neutrino Search

Mibe and G-2/EDM collaboration

Aoki and DeeMe collaboration

Shimomra and MuSEUM collaboartion

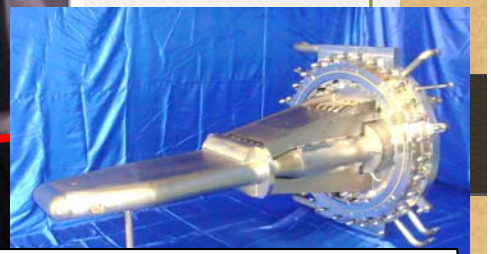
Makimura, Matoba, Kawamura and Muon section

Haga and Neutron source section

experiments & targets at J-

ADS target at TEF (future plan)
- ☐ Liquid metal, Lead-Bismuth Eutectic
- ☐ Irradiation database in Liquid metal

Muon target at MLF
- ☐ Rotating Target, Graphite
- ☐ Materials and Life Science
- ☐ High Energy Physics
  - ✓ Muon-Electron Conversion (DeeMe)
  - ✓ Muonium Hyperfine (MuSEUM)
  - ✓ G-2/EDM



Neutron target at MLF
- ☐ Liquid metal, Mercury
- ☐ Materials and Life Science
- ☐ High Energy Physics
- ✓ sterile neutrino

COMET target at HEF
- ☐ #1: Graphite
- ☐ #2: Tungsten
- ☐ High Energy Physics
- ✓ Muon-Electron Conversion

- ✓ Hadron target
- ✓ Neutrino target

Introduced by Ishida

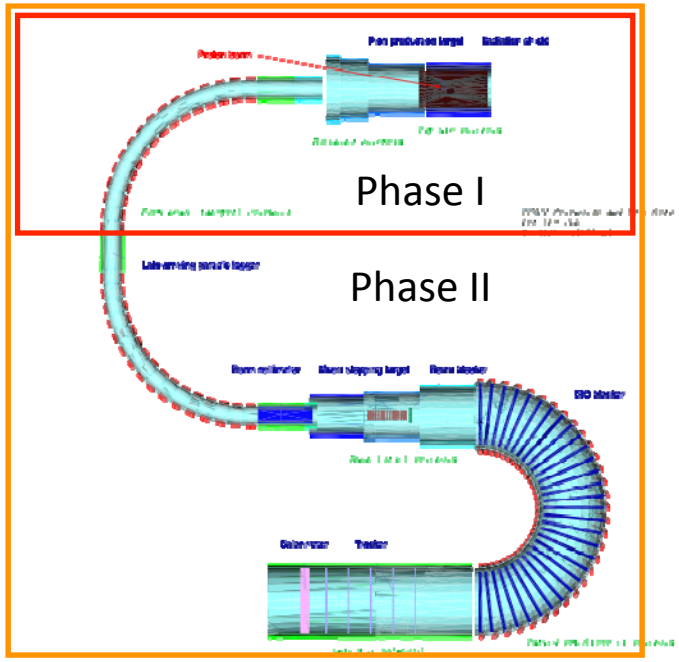
by Mihara

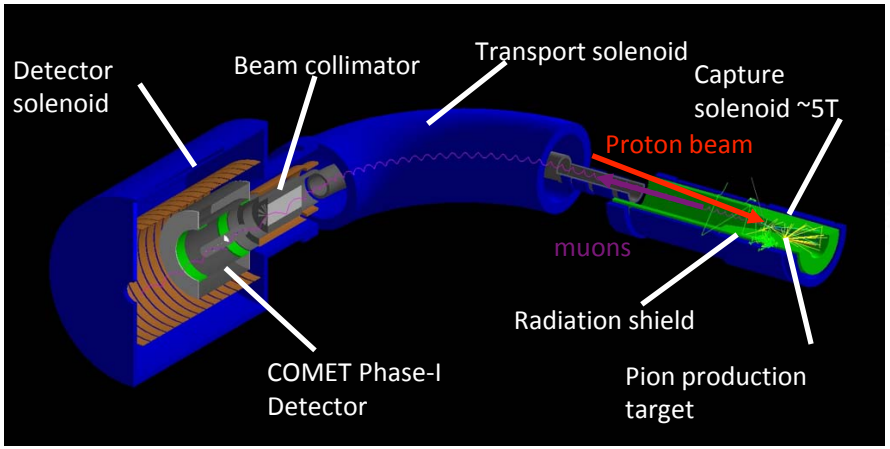
COMET Phase I & II

Beam loss:

- Phase 1: 100 W graphite
- Phase 2: 4 kW tungsten

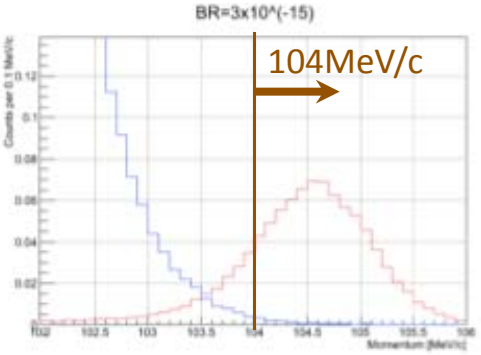
- Phase I
  - Detailed understanding of the beam background and achieving the sensitivity of < 10^{-14} (100 better than the current limit)
  - **8GeV, 3.2kW beam, ~100-days DAQ (Graphite as a primary target)**
- Phase II
  - 8GeV, 56kW beam, 1-year DAQ (Tungsten as a primary target)
  - COMET final goal Sensitivity < 10^{-16}
- Proton beam extinction (w/o extraction) of 10^{-12} has been already achieved (Req. < $10^{-9\sim10}$)





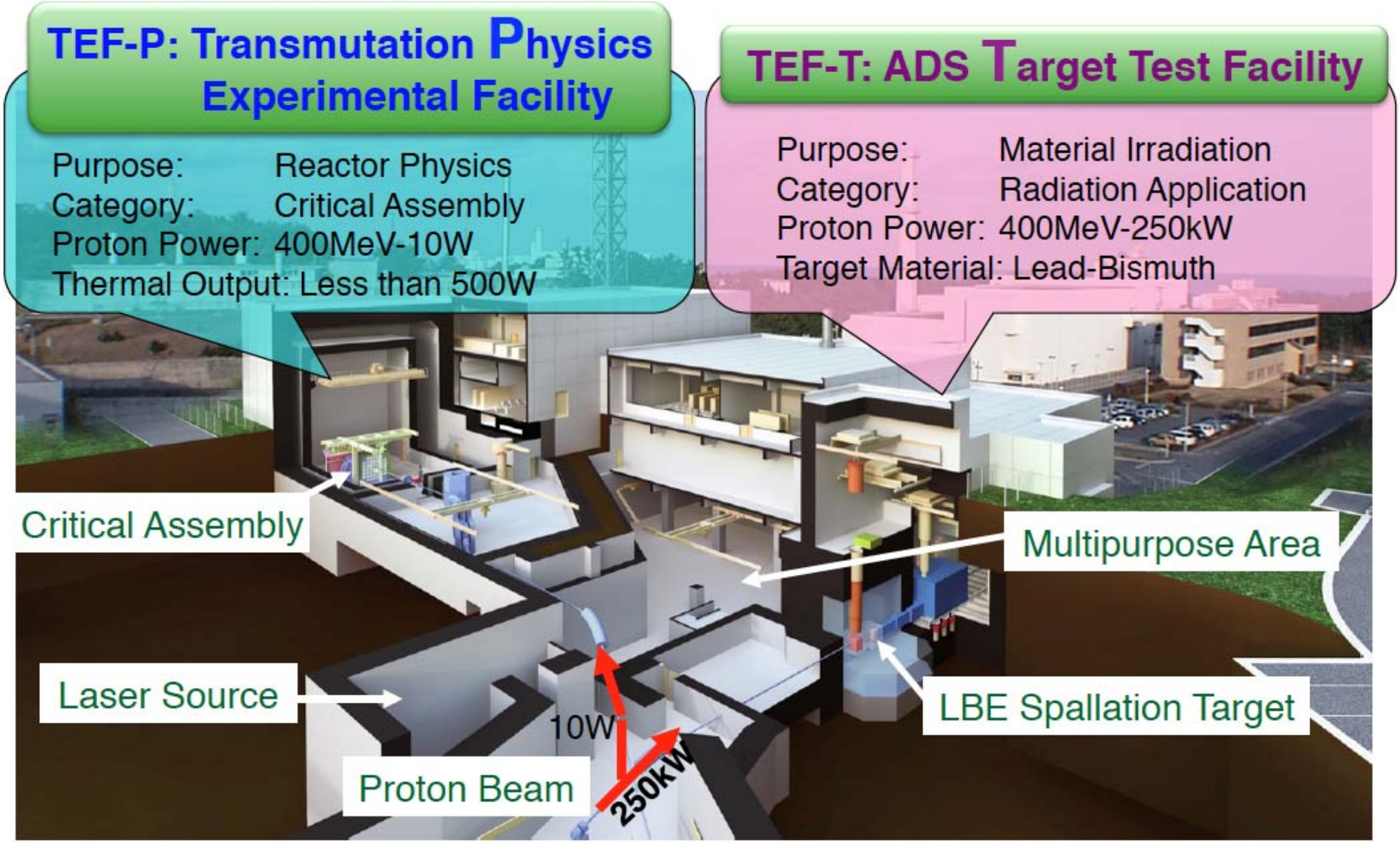
Phase I background

0.03 BG expected
In 7.8x10^6 sec running time

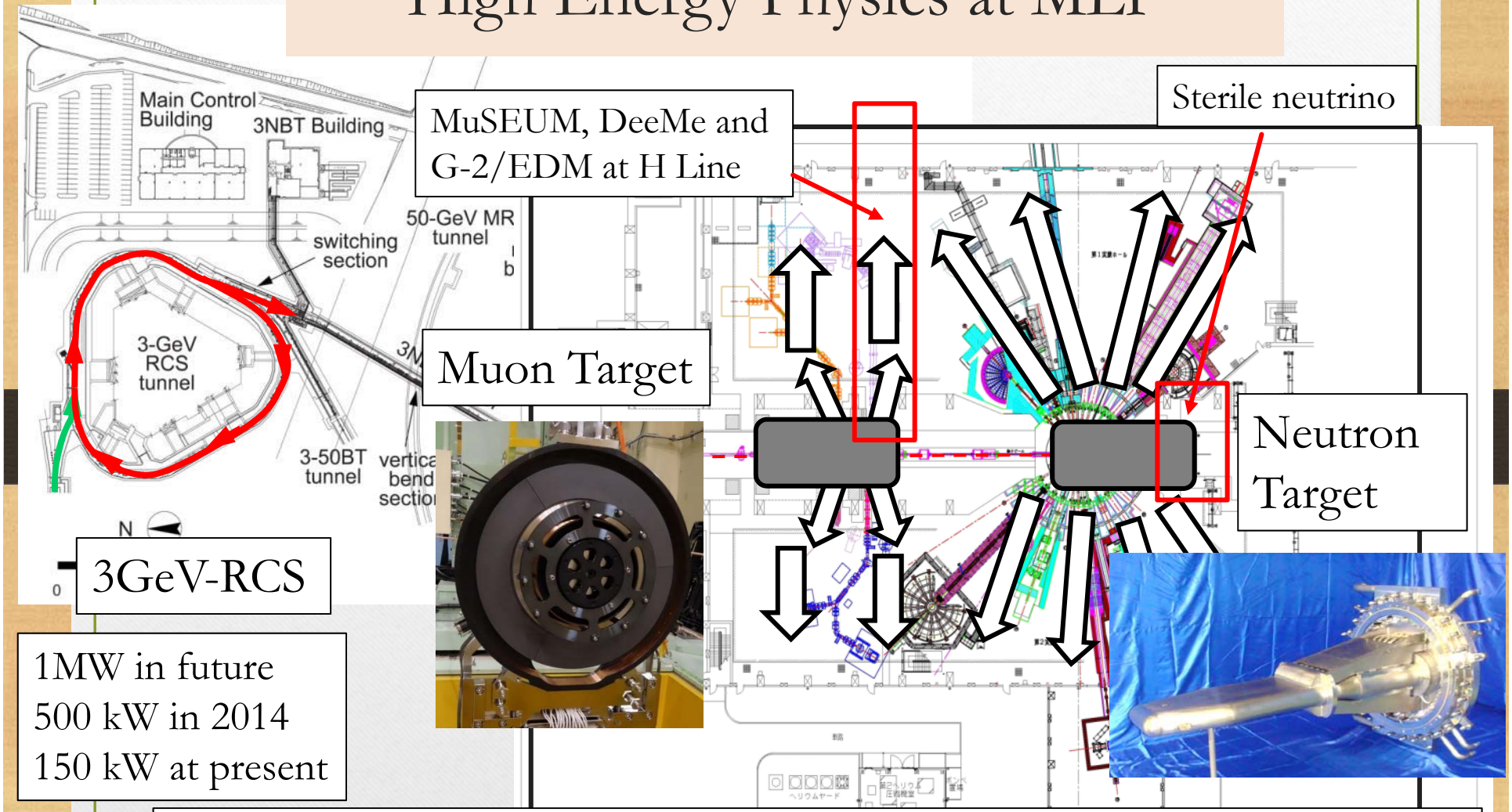


Phase I
2013-2015
Facility construction
2013-2018
Magnet construction & installation
2018-2020
Eng. run & Physics run
Phase II
Eng. run in 2022-

Transmutation Experimental Facility (TEF)



Neutron & Muon target at MLF
High Energy Physics at MLF



1MW in future
500 kW in 2014
150 kW at present

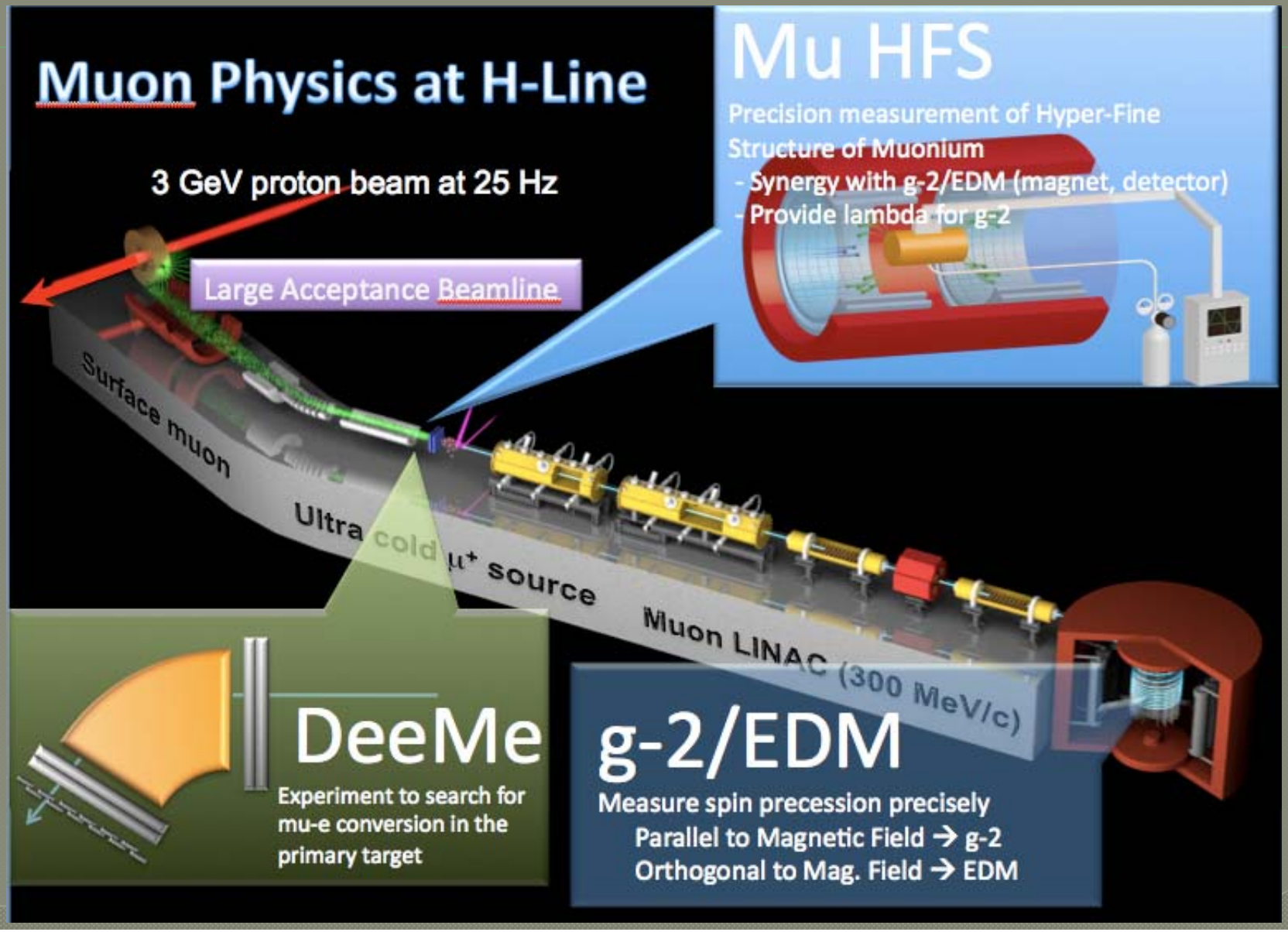
MLF was constructed for material science.
Activities of HEP has been started taking advantage of characteristic of proton beam.

Materials and Life Science Experimental Facility (MLF)

Characteristic of proton beam at MLF (1 MW proton beam)

- Species: proton
- Energy: 3 GeV (efficient for neutron & muon production)
- Pulse intensity: 83 tera proton / double pulse
- Average intensity: 2.0 peta proton / sec (=333.333 microA)
- Beam pattern: 25 Hz double pulse separated by about 600 ns with 100 ns width (FWHM) for each pulse
- Spot size: $\sigma x = \sigma y = 3.5$ mm on muon target
  18cm(W) x 7cm(H) broaden beam with low beam halo for neutron target

H-line


Muon Physics at H-Line
3 GeV proton beam at 25 Hz
Large Acceptance Beamline
Surface muon
Ultra cold μ+ source
Muon LINAC (300 MeV/c)
Mu HFS
Precision measurement of Hyper-Fine Structure of Muonium
- Synergy with g-2/EDM (magnet, detector)
- Provide lambda for g-2
DeeMe
Experiment to search for mu-e conversion in the primary target
g-2/EDM
Measure spin precession precisely
Parallel to Magnetic Field → g-2
Orthogonal to Mag. Field → EDM

DeeMe: μ-e Conversion Search at H line, MLF

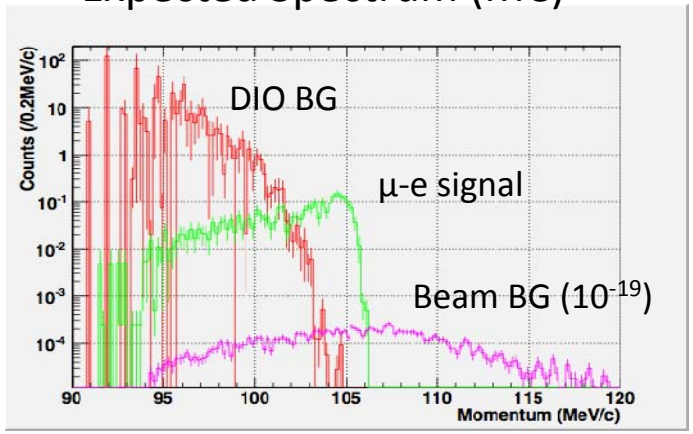
by Aoki

Novel Idea: μ-e Conversion in the primary production target itself

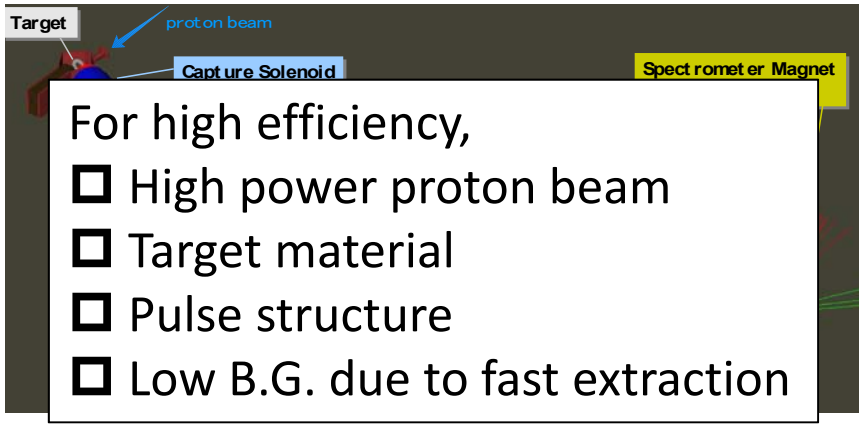
S.E.S: 1×10^{-13}(**Graphite Target**), 5×10^{-15}(**SiC Target**)

- Current Upper Limits:
  - BR[μ^- Ti→ e^- Ti] < 4.6×10^{-12}@TRIUMF
  - BR[μ^- Au→ e^- Au] < 7×10^{-13}@PSI
- Status
  - S-type Program: Stage-2 Approved in 2014 by J-PARC MLF PAC
  - Ready to go once H-line has constructed

Expected Spectrum (MC)



Signal Region: 102.0 -- 105.6 MeV/*c*



For high efficiency,

- ☐ High power proton beam
- ☐ Target material
- ☐ Pulse structure
- ☐ Low B.G. due to fast extraction

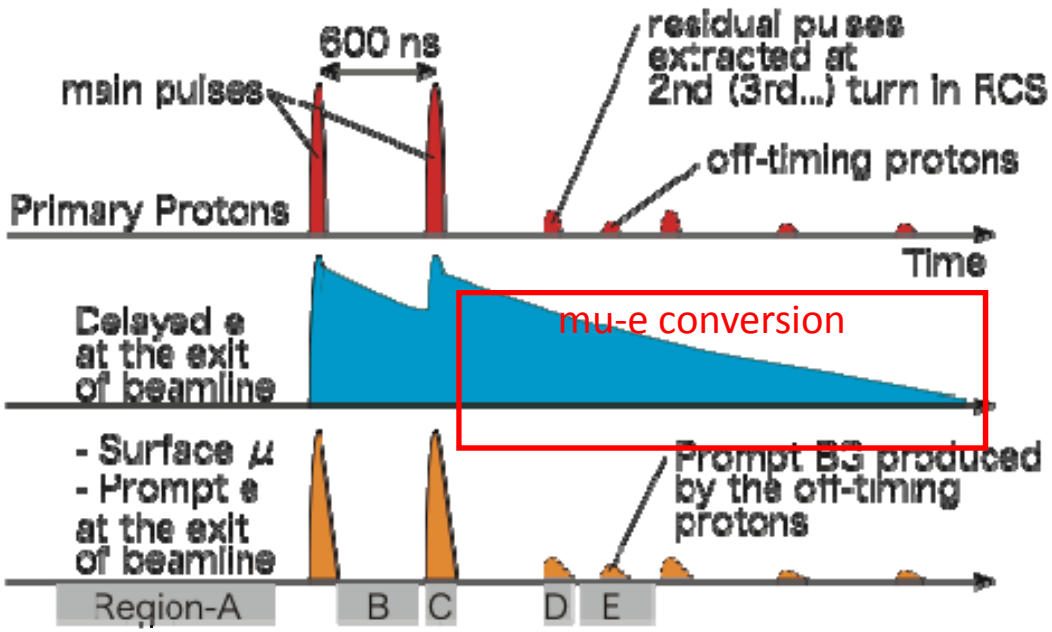
μ-e conversion: rare process

Suppress Backgrounds

RCS: High-Purity Pulse

(D+E)/C < 8×10^{-19}

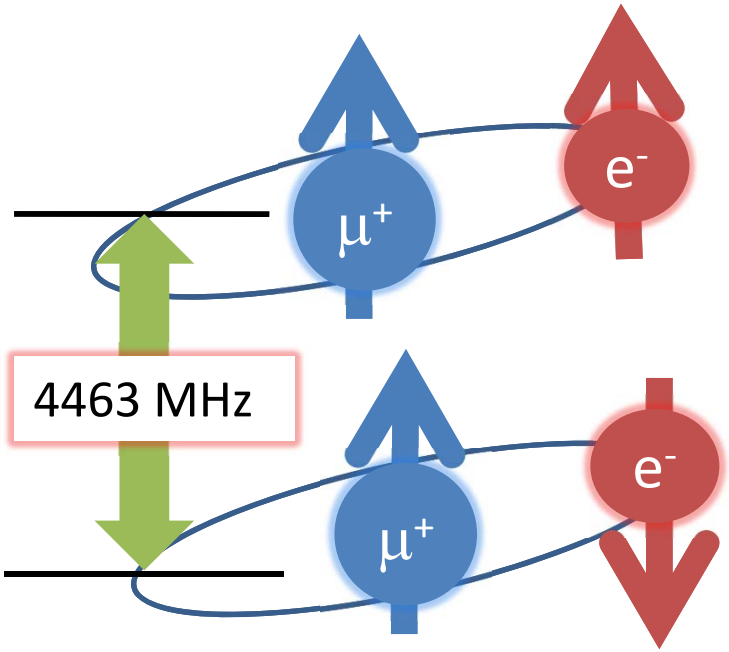
Very small "Beam BG" with RCS

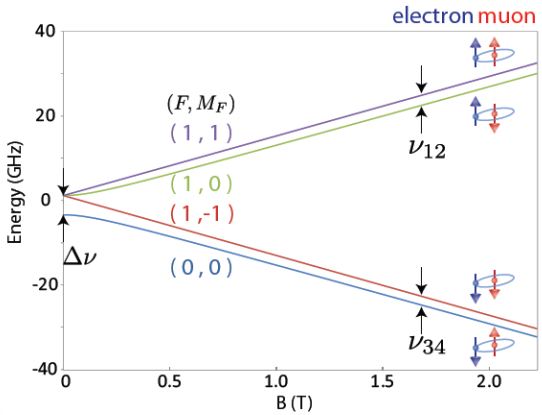


MuSEUM: Mu Hyperfine Structure

$$\mathcal{H} = h\Delta\nu \mathbf{I}_\mu \cdot \mathbf{J} - \mu_B^\mu g'_\mu \mathbf{I}_\mu \cdot \mathbf{H} + \mu_B^e g_J \mathbf{J} \cdot \mathbf{H}$$

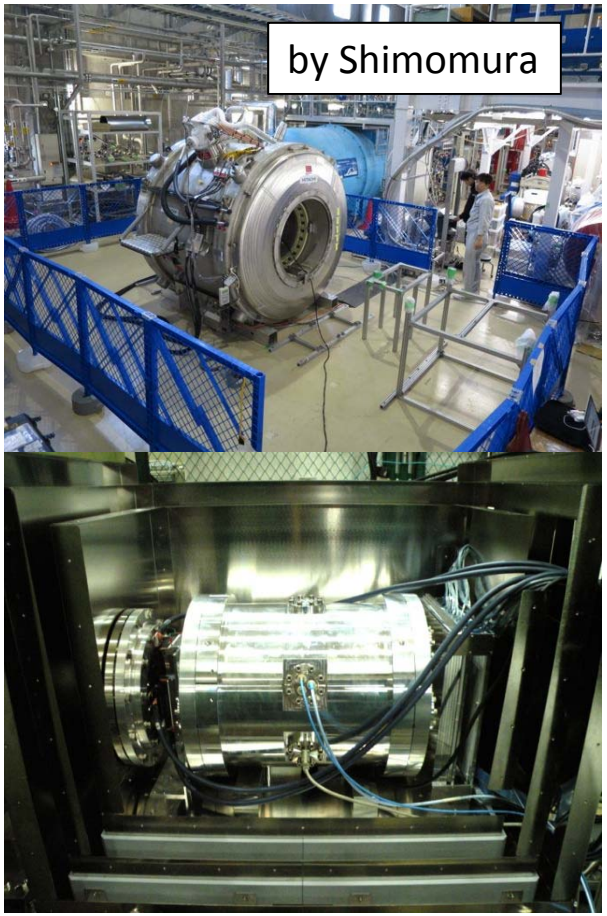
$\Delta\nu_{HFS}$: Mu Hyperfine Structure Zeeman Splitting

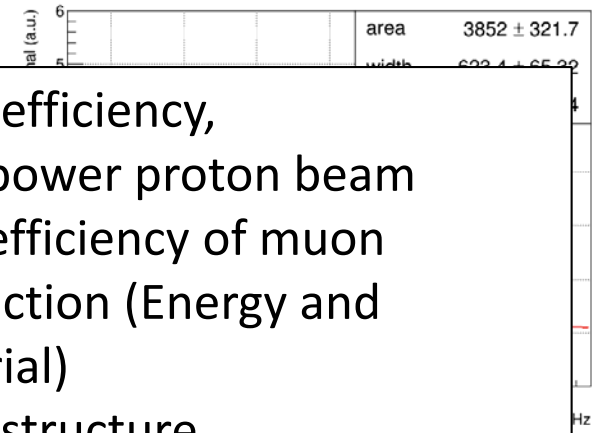




$\nu_{12}+\nu_{34}=\Delta\nu_{HFS}$

$\nu_{12}-\nu_{34} \propto \mu_\mu/\mu_p$





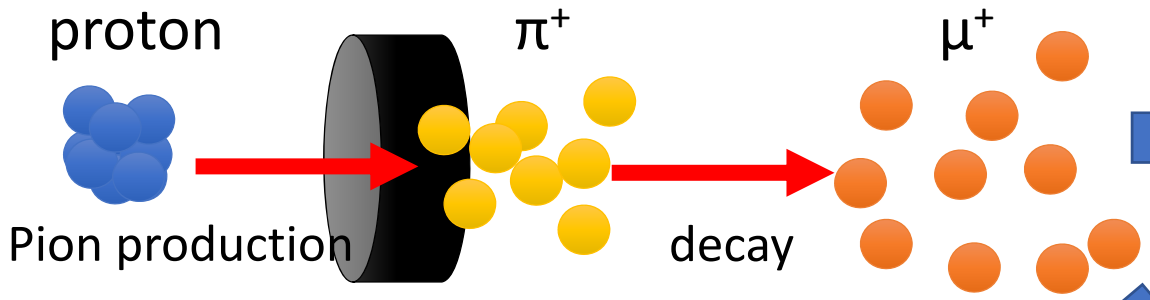
Pure leptonic system
(No composite particle)

The most precise test to the bound C
Basic input parameter for muon g-2
Probing for new physics

For high efficiency,
- ☐ High power proton beam
- ☐ High efficiency of muon production (Energy and material)
- ☐ Pulse structure

Precise measurements of Muon g-2 and EDM at MLF

by Mibe



Conventional muon beam

emittance

~1000π mm ·mrad

Strong focusing to store
Muon loss during storage
BG π contamination

Cooling & acceleration

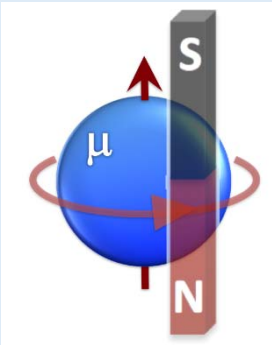
J-PARC g-2/EDM

μ+ *emittance*

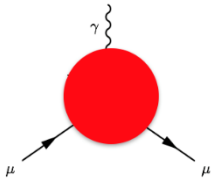
1π mm ·mrad

Free from any of above

- **Anomalous magnetic moment (g-2)**
  - Independent test of the BNL anomaly



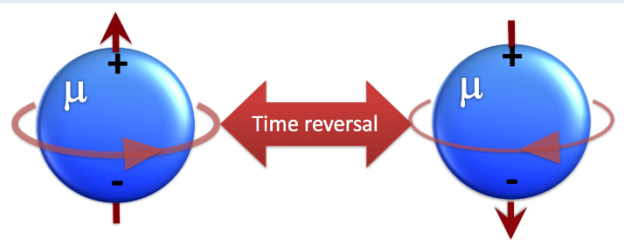
$$a_\mu = \frac{g-2}{2} =$$



Standard model	11 659 182.8 (4.9) x 10^{-10} (0.42ppm)
Previous Exp. (BNL)	11 659 208.9 (6.3) x 10^{-10} (0.54ppm)
Exp. – Prediction(SM)	26.1 (8.0) x 10^{-10} (3.3 σ)

Goal: Δa_μ =0.1ppm

- **Electric dipole moment (EDM)**
  - In search for CPV in lepton sector

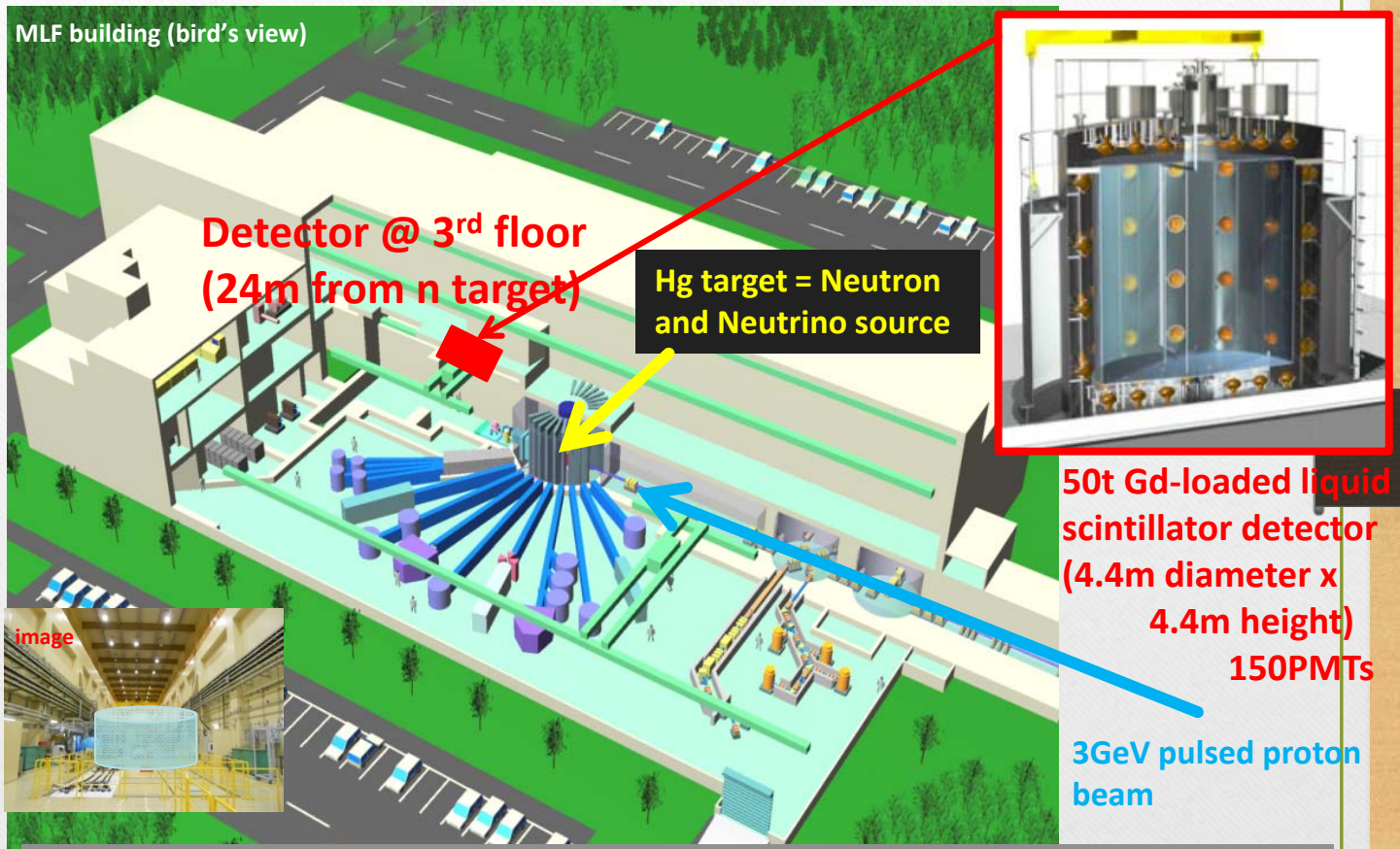


Goal:
ΔEDM=10^{-21} e•c

For high efficiency,
- ☐ High power proton beam
- ☐ High efficiency of muon production (Energy and material)
- ☐ Pulse structure

by Maruyama

Sterile Neutrino Search by neutron target at J-PARC MLF



- Recently, Technical Design Report was submitted to arXiv.
  arXiv:1705.08629 [physics.ins-det]
- Aim to start the experiment around end of JFY2018.

Searching for neutrino oscillation : $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ with baseline of 24m.
no new beamline, no new buildings are needed → quick start-up

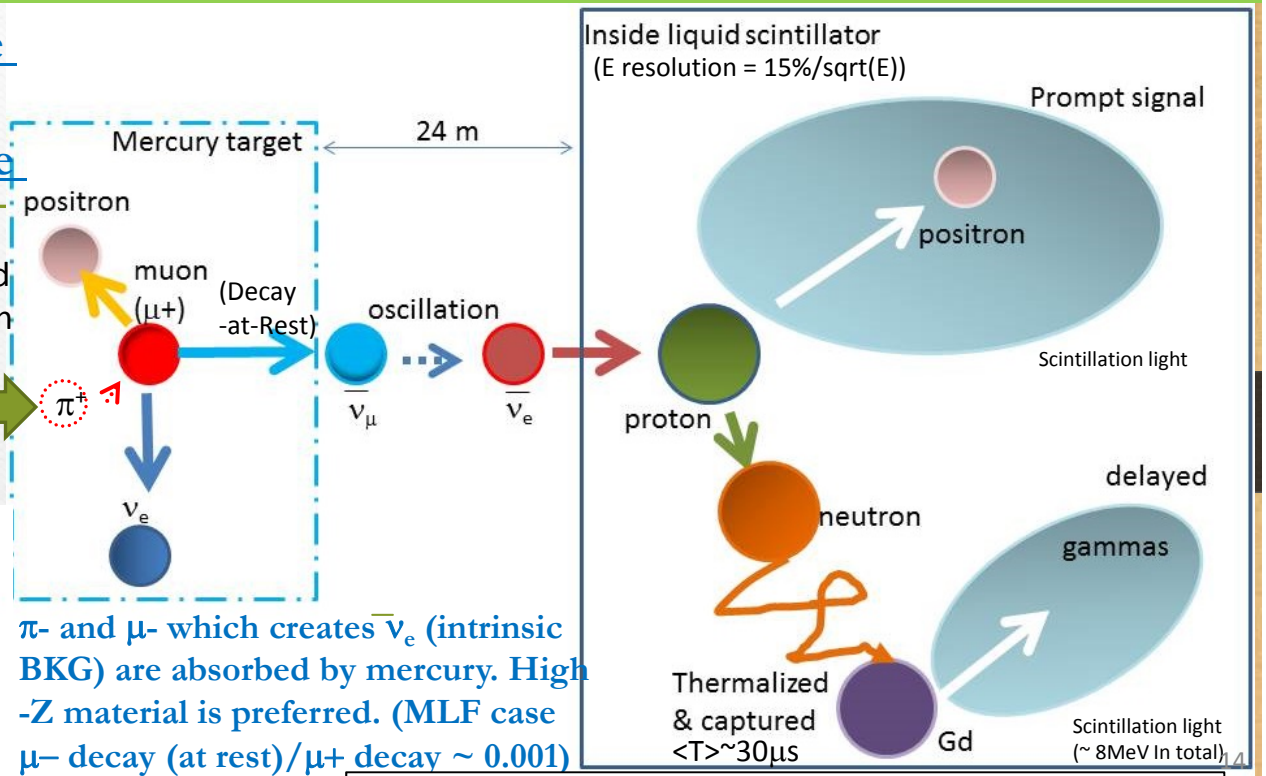
by Maruyama

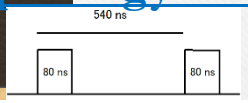
Principle of experiment and requirement for p beam

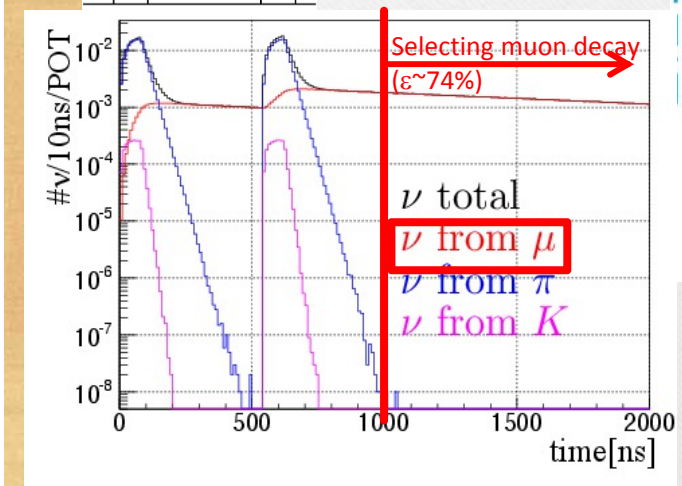
- Using timing information, we can select the ν from μ+ only. (bottom), we need shorter pulse beam than muon lifetime.
- π+ (and μ+) must be stopped at the target.

→ p energy must be 1~3GeV

3GeV pulsed proton beam







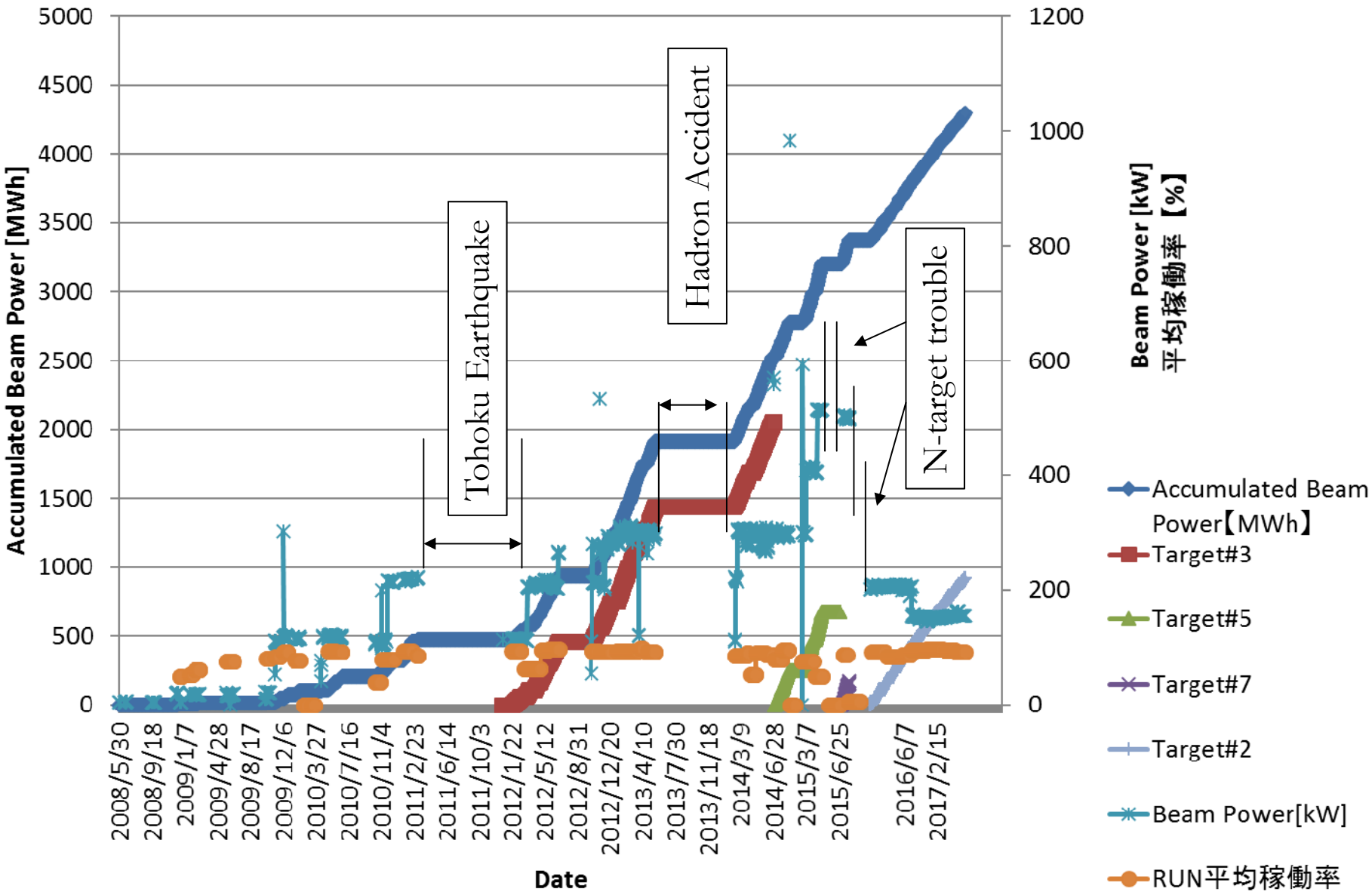
π- and μ- which creates $\bar{\nu}_e$ (intrinsic BKG) are absorbed by mercury. High -Z material is preferred. (MLF case μ– decay (at rest)/μ+ decay ~ 0.001)

- Neutrino progr
  Multi MW beam
  after current desi

For high efficiency,

- ☐ High power proton beam
- ☐ High efficiency of muon production (Energy and material)
- ☐ Pulse structure

Proton beam operation at MLF

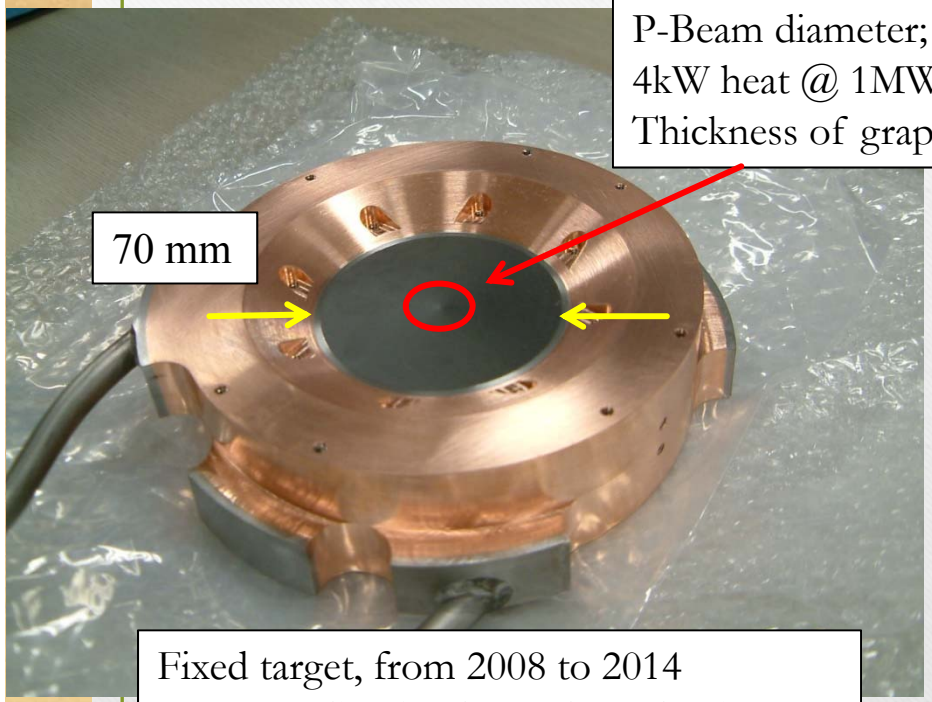


Muon target at MLF

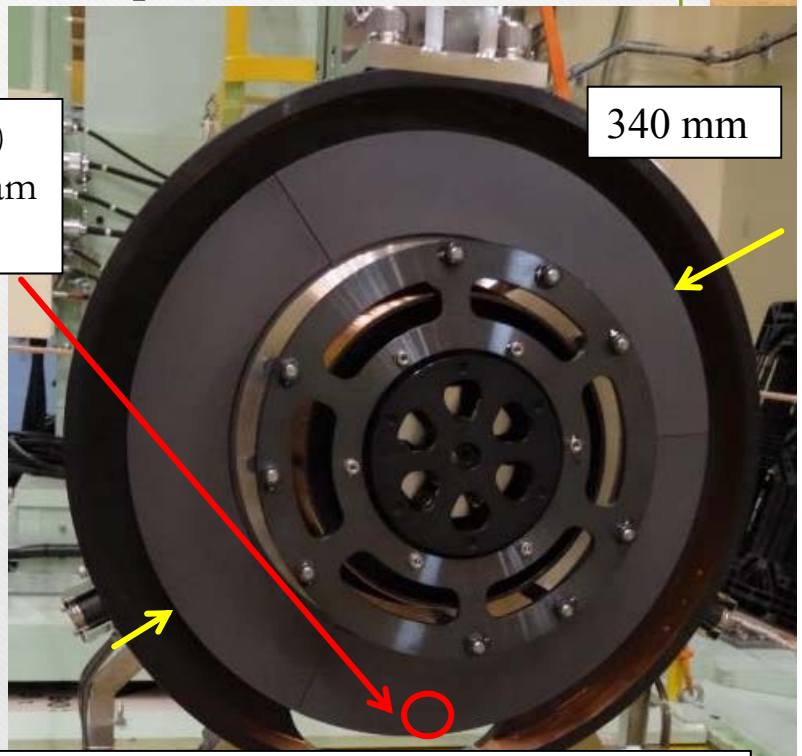
- Target material is polycrystalline graphite, IG-430U.

Thermal resistance (up to 1900 K), Resistance to thermal shock

- Fixed target is replaced with rotating target to disperse the radiation damage of graphite.



P-Beam diameter; 14 mm (2σ)
4kW heat @ 1MW proton beam
Thickness of graphite 20 mm



Fixed target, from 2008 to 2014
Water-cooling by thermal conduction
Lifetime: Irradiation damage of graphite
1 year at 1 MW operation

Rotating target, from 2014
Cooling by thermal radiation
Lifetime: Bearings
Aiming Lifetime: 10 years at 1 MW operation

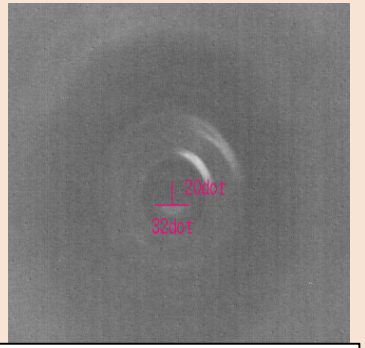
New developments for Muon target at MLF

- Diagnostic system for monitoring and foresight of failure

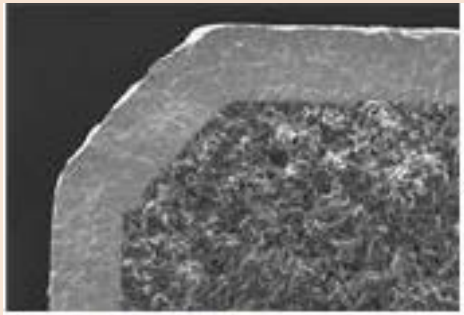
Gases analysis, In-situ temperature measurement, Vibration monitoring

- Material development~ SiC coated graphite and SiC/SiC composite

Infrared camera

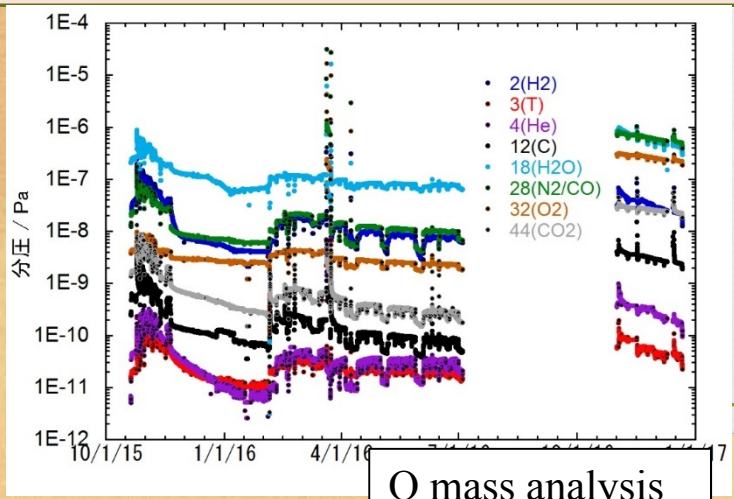


RT testing w/o beam



SiC-coated graphite with RaDIATE & US^JP collaboration

Presented in Session 2



Q mass analysis

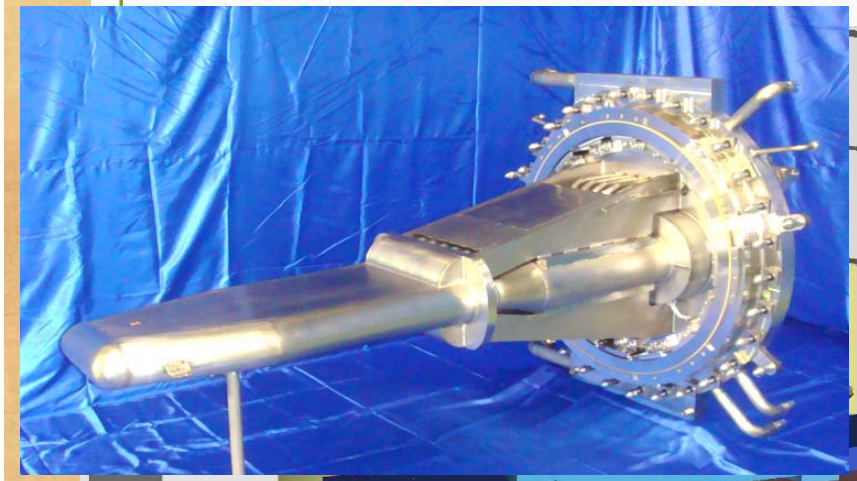
1/3 model for muon target

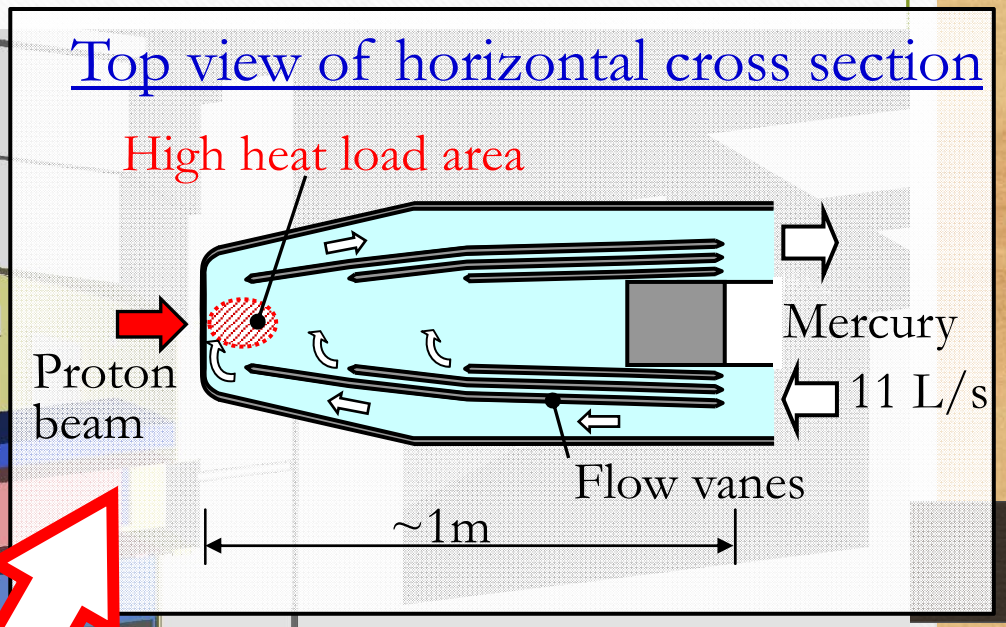
SiC/SiC composite for resistance to thermal shock, by Muroran Institute of Technology

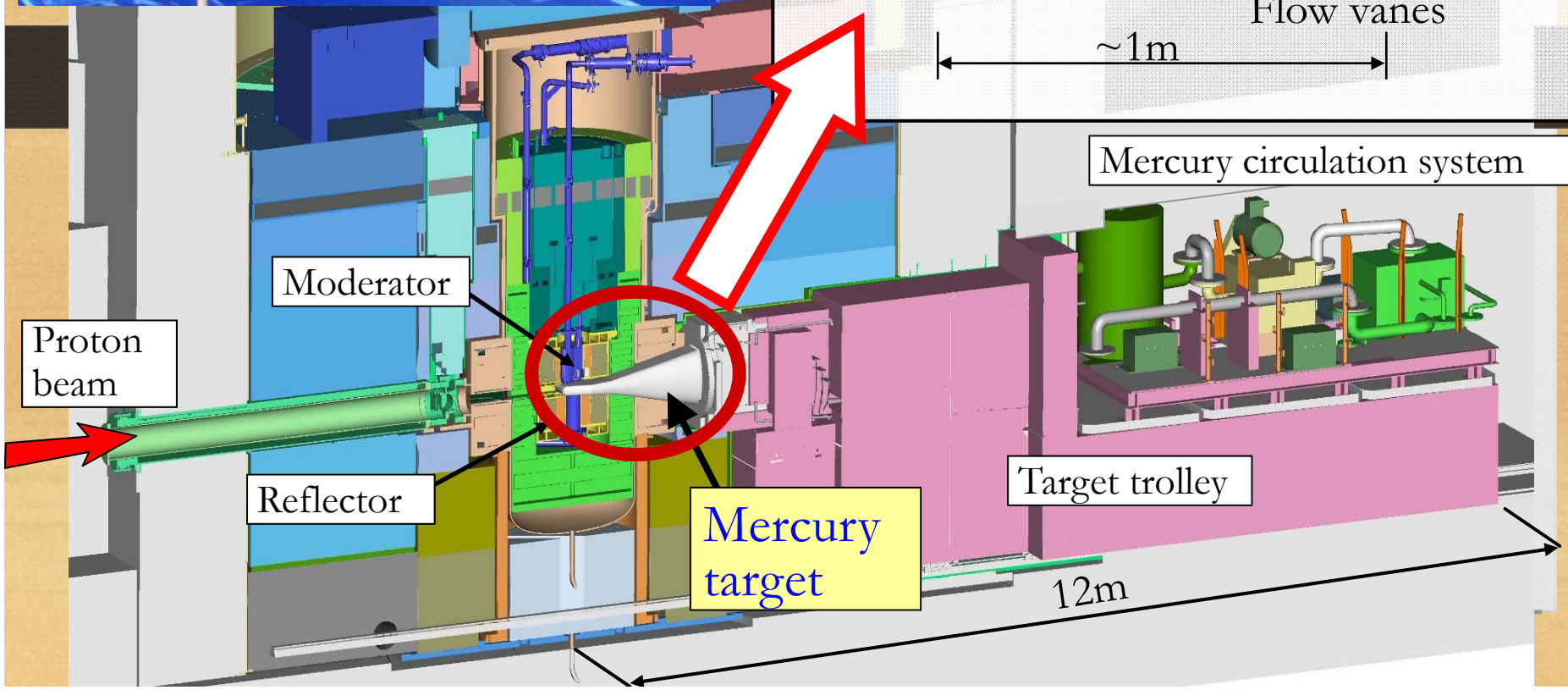
Supported by Kakenhi

by Takada & Haga

Neutron Target at MLF



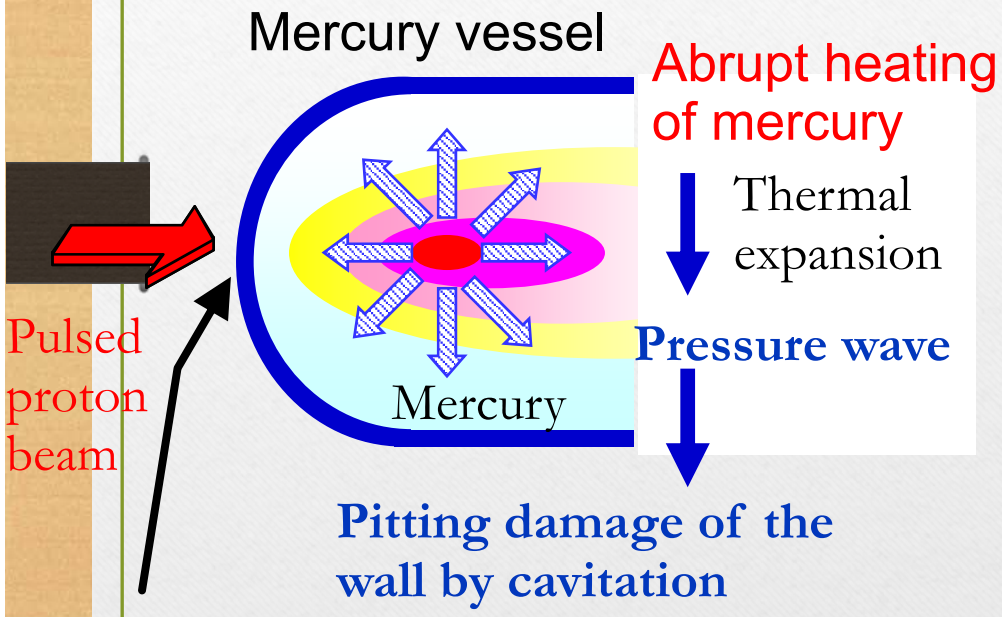




by Takada & Haga

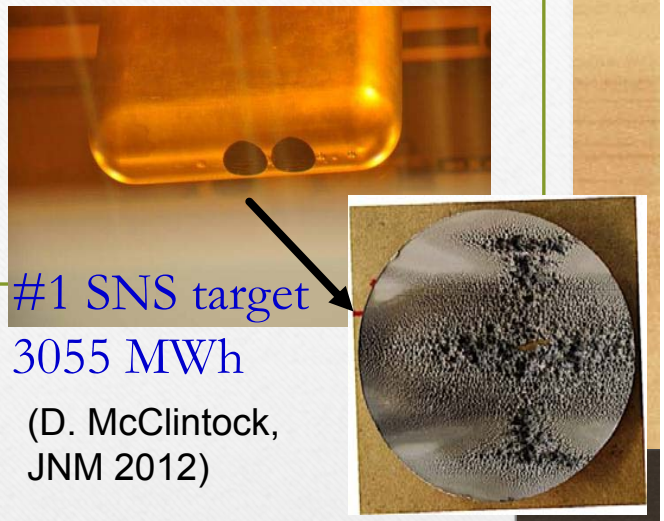
Pitting Damage of Mercury Target

Serious issue arose in the combination of the liquid metal target and intense short pulse beams.

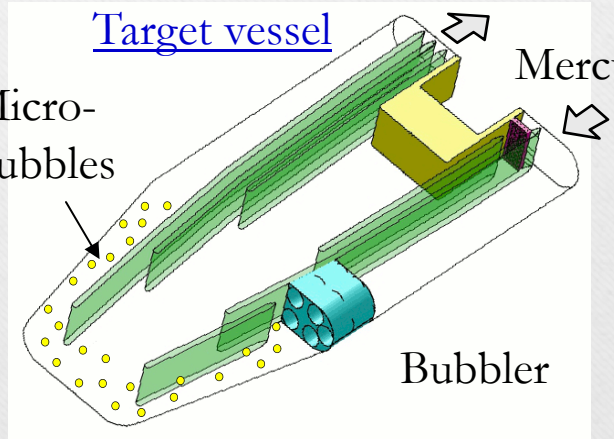


Beam window (Thickness : 3 mm)
Most vulnerable to pitting damage

Actual pitting damages



(D. McClintock, JNM 2012)

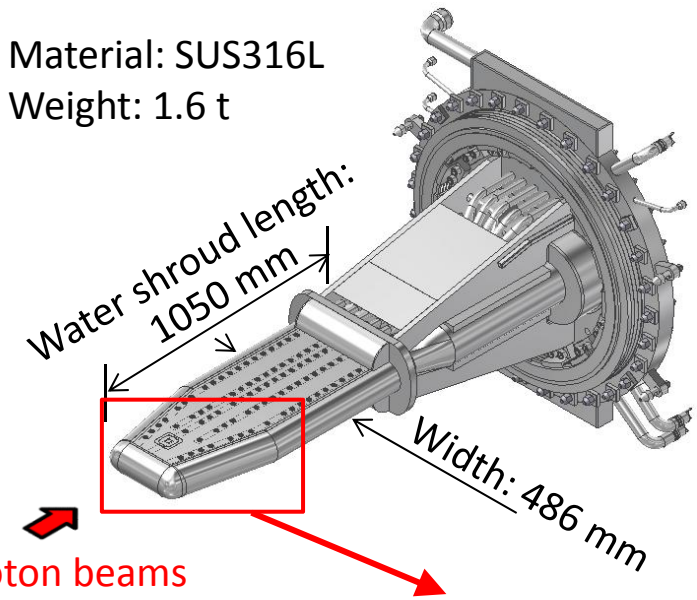


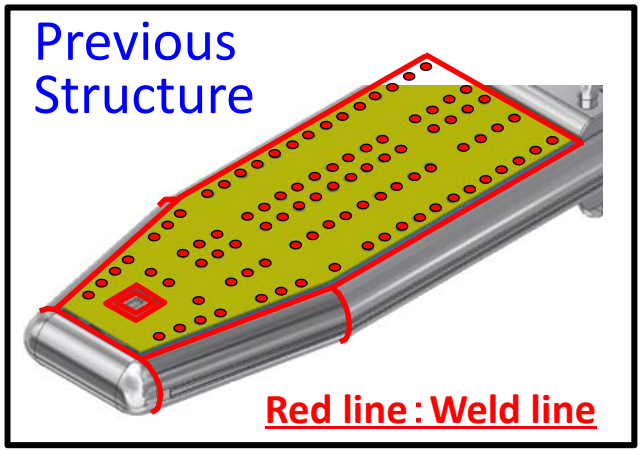
The developments of bubbling system to mitigate pressure waves was demonstrated.

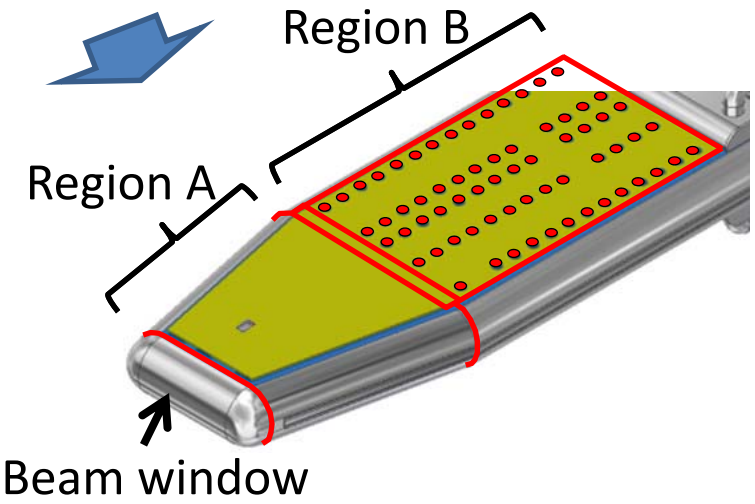
Target Structure and Failures Occurred in 2015

by Takada & Haga

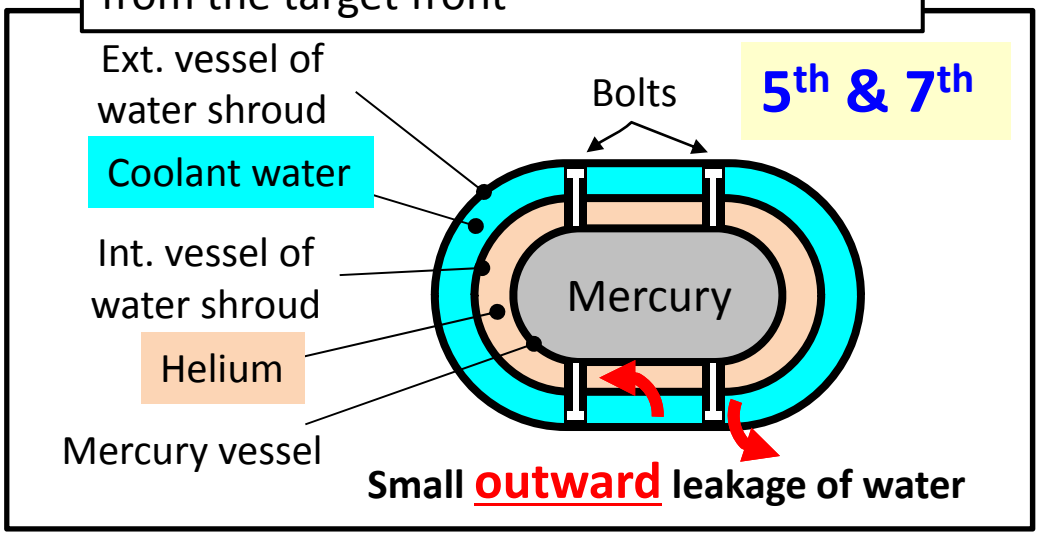
Material: SUS316L
Weight: 1.6 t







Vertical cross--section of targets viewed from the target front



Drastic reduction of weld: 55%

Monolithic structure as much as possible

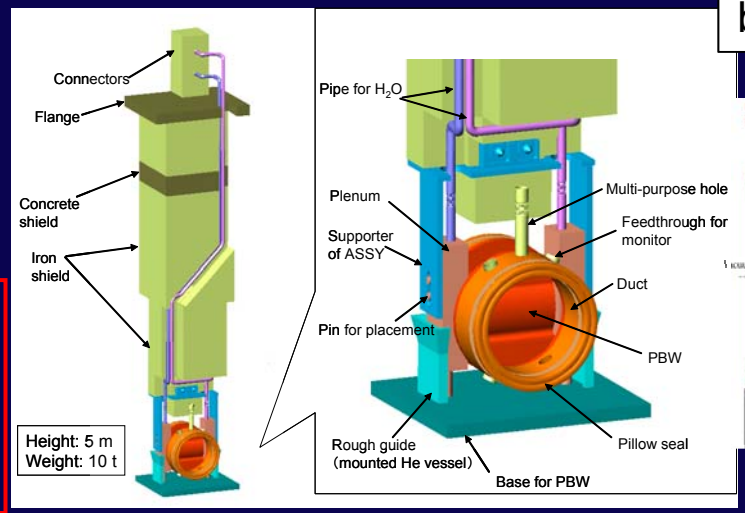
More careful quality assurance

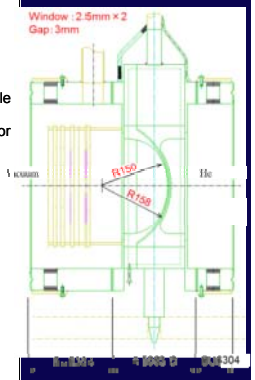
Proton Beam Window (PBW) at MLF

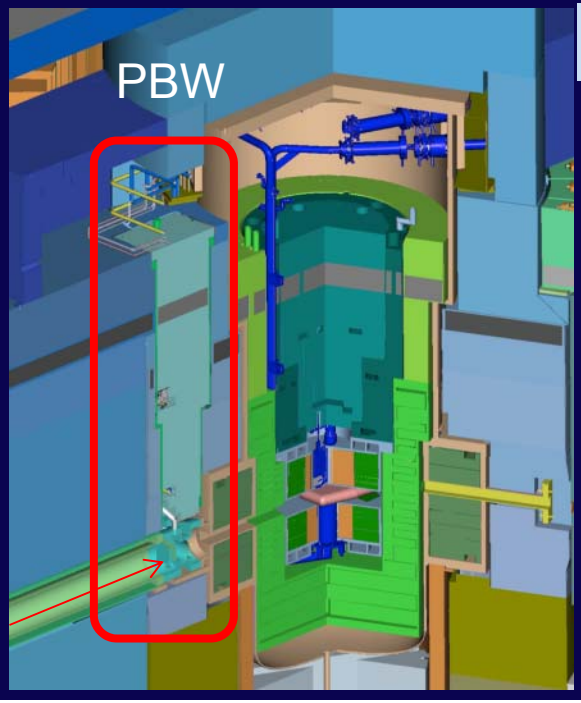
- Boundary between accelerator (vacuum) and target station (helium)
- In 2013, PBW #1 exchanged to #2
- Aluminum alloy (AL5083, t 2.5 mm x 2)
- Deploying beam monitors
- Conservative lifetime ~ 2 years for 6 $\mu A/cm^2$ at 1MW (based on SINQ PIE data : Hydrogen production 3300 appm)

S. Meigo et al., J. Nucl .Mat. 450, pp. 141-146 (2014)

by Meigo







RH test for new PBW

Inspection PBW #1 after irradiation

Vacuum side

60cm

Helium side

Erosion spots were found, which might be caused by air leak of vessel in early date, and are not found a new PBW.

Requirements from physics ~ Intensity (as high as possible), Energy (to produce M&N), Pulse structure (shorter than life of muon 2.2 us), Target Material

- Robustness of target
  - ✓ Target engineering to disperse the heat load and radiation damage

    Solid rotating target method and liquid metal target method
  - ✓ Mechanical engineering and quality assurance
- Irradiation resistance of target or window material
  - ✓ Promotion of Irradiation campaign and PIE testing
- Resistance to Pulsed heating
  - ✓ Measures against cavitation and Material development
  - ✓ Pulsed heating Testing, e.g. HiRadMAT
- Diagnostic system for Monitoring and foresight of failure

Thank you for your attention!!